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varian/lexington vacuum division
121 hartwell avenue / lexington / massachusetts 02173

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SLICING OF SILICON INTO SHEET MATERIAL

Silicon Sheet Growth Development for the Large Area Silicon Sheet Task of the Low Cost Silicon Solar Array Project

TENTH QUARTERLY REPORT

By

J. R. FLEMING

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Varian Associates
Lexington Vacuum Division
121 Hartwell Avenue
Lexington, Massachusetts 02173

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S-100-Q10

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1.0 SUMMARY

We have defined the limits of blade tolerances. The standard blades are T-2 thickness tolerance: T-0 blades are unacceptable. Further testing is necessary to demonstrate feasibility or infeasibility of T-1 blades.

Good results have been obtained by using a slurry fluid consisting of mineral oil and a lubricity additive. Cost would be about $.25 per gallon per run, 1/4 of the cost goal. Adjustments of the formulation and fine tuning of the cutting process with the new fluid are necessary.

Test results and consultation indicate that the blade breakage we have encountered with water based slurries is unavoidable. We have not totally abandoned the idea of water based slurry because of the great potential benefits, but in view of our experience, we do not intend to expend much further effort investigating such slurries.

Two full capacity (974 wafer) runs have been made on the large prototype saw. Both runs resulted in extremely low yield, however, the reasons for the low yields were lack of proper technique rather than problems with machine function. The machine operates extremely well, and results will improve as we gain experience.

Finally, the tests on the effect of amount of material etched off of an as-sawn wafer on solar cell efficiency have been completed. The results agree with previous work at JPL in that the minimum material removed per side that gives maximum efficiency is on the order of 10 µm.

2.0 PROGRESS

2.1 Blade Tests

Continuing our investigation of cheaper blades, we ran Test #2-1-08 using a blade pack made from T-0 thickness tolerance blades. The thickness tolerances on these blades are 60% greater than the tolerances on our standard T-2 tolerance blades.

Blade thickness, spacer thickness, and all other conditions were standard. Severe wafer breakage occurred throughout the run, and no wafers survived. Cutting time was 40.5 hours due to feed sticking (the test was run on the bounce fixture machine because of availability). Blade wear was low (25% less than usual) but blade side wear was high (1/3 the blade thickness).

We repeated the test in Test #2-1-09, except we removed the bounce fixture. The results of the two tests were identical. We concluded that T-0 tolerance blades cannot be used to wafer 100 mm diameter silicon. We will continue our investigation of T-1 tolerance blades.

An earlier test (#2-1-06) in which blade elongation was increased 20% yielded disappointing results in that wafer dimensional parameters were the same as or worse than average. This result seemed so contra-intuitive that we repeated the test in Test #2-1-10. Blade elongation was increased 20% (to 3.05 mm, 0.120 in.). All other conditions were standard.

Cutting time was somewhat long, 41 hours. Yield was 90%. Worst mean values of wafer dimensional parameters were as follows: nonlinear thickness variation 52 μm (0.002 in.), centerline bow 92 μm (0.0036 in.). Comparable results from other runs using standard elongations were 65 μm (0.0026 in.) NTV and 133 μm (0.0052 in.) bow. Other parameters such as thickness standard deviation and non-worst case NTV and bow were also improved. (Due to the nature of the sawing process, wafer dimensional parameters differ between the with-stroke and perpendicular-to-stroke directions.)

In two runs with the increased elongation, we have now obtained one average run and one better than average run. More testing is necessary to define the average result with the greater elongation. The increased elongation is very attractive because it improves one attribute of the process (wafer dimensional parameters) without degrading any other attributes (setup time, cost, etc.).

2.2 Slurry Tests

As discussed in earlier reports, mineral oil slurries work quite well except drag forces are too high. Test #2-3-20 used a mineral oil slurry mixed 10:1 by volume with lard oil, a standard lubricity additive. All other conditions were standard.

Drag forces were reduced, as shown by the reduced current draw in the motor. However, drag forces were still higher than with PC oil slurries. Several fuses blew during the run, and all wafers had broken by the time the cut was half finished, and the run was halted after 18.5 hours.

The lubricity approach seemed promising, and since good cutting was obtained in Test #2-3-19 (unthickened water), we decided to try thinner mineral oils with lard oil additive.

Test #2-3-23 was run using thin (100 SUS) mineral oil with lard oil added. Cutting time was reasonable, 36.75 hours. Yield was very low, 12%. Wafer dimensional parameters were poor, but not terrible; NTV was 120 μm (.0047 in.) and bow was 235 μm (.0093 in.). The cause of the low yield and high bow are unknown, but both problems probably stemmed from the same source. The drag force and fuse blowing problem was completely eliminated.

As a baseline comparison, we ran Test #2-3-26 which was a duplicate of #2-3-23 except that no lard oil was added. Cutting time was long, 61 hours. Yield was 73%. NTV was 100 μm (.004 in.) and bow was 256 μm (.012 in.). No fuses blew, but the ingot was noticeably warmer than usual during the cut.

Two more tests were run to test the effect of parameter variation on thin mineral oil-lard oil slurry. Test #2-3-25 was run under the same conditions as #2-3-23 except that we changed our machine setup procedure slightly. The standard method is to tension the blade pack and then align the blades with the stroke. We reversed this order: the procedure was much more difficult and time consuming, but probably resulted in better alignment of the central blades.

Cutting time was again long, 61 hours. Yield was 49%. Slice taper and bow were 92 μm and 128 μm respectively, an improvement over Test #2-3-23. However, the bow and taper were still somewhat high, and we feel that the difficulty of the different setup procedure is so high that the improvement achieved is not worth the extra work.

Since cutting time with mineral oil-lard oil slurries had been so long, we tried to speed up the cut in Test #2-3-27 by increasing the abrasive/vehicle mix to 0.48 kg/l (4 lb/gal). The reason for this change was our suspicion that the tortuous path followed by the slurry in returning from the ingot to the bucket allows buildup of settled sludge (when a non-suspension vehicle is used). Thus, the abrasive/vehicle ratio is constantly decreasing. Every 8 hours, we had been scraping up the sludge and remixing, but the ratio still varied during each 8 hour period. The increased amount of abrasive in Test #2-3-27 was intended to compensate for this settling.

As we hoped, cutting time was much improved, 26.5 hours. Unfortunately, yield was very low (5% or 7 wafers). The surviving wafers were excellent, with very low bow and taper. Although the wafers were too few to form a statistically significant sample, their high quality indicates that the cause of the low yield was not severe blade wander.

We feel that 100 SUS mineral oil with lard oil additive is an excellent low cost slurry vehicle. Cost is about $1.20/gal in bulk. Due to the lack of suspension power, a few days settling allows one to easily draw off about 80% of the vehicle for reuse, reducing the cost of vehicle to about $.25/gal/run. This is significantly better than the $1/gal/run cost goal. Another advantage of this system is that the sludge can be resuspended in a less viscous medium such as water, making abrasive reclamation more convenient.

We feel that the problems encountered can be solved in time. It should be noted that the 7176 saw (which is the replacement for the 686) and the prototype both have much simpler slurry return paths, so sludge build-up should not be a problem.

We have continued our investigation of water based slurries. Test #2-3-22 was run using a slurry of distilled water and abrasive, with no other additives. Other conditions were standard. This test was intended to provide a baseline by which to measure the performance of the various corrosion inhibitors we have tried or will try.

Cutting rate was reasonable, about .053 mm/min (.0021 in/min). At .23 mm (.91 in.) cut depth, blade breakage was so severe that we stopped the test. The blades were visibly rusted immediately after the test, even on the portions that were continuously abraded.

It is tempting to conclude that the corrosion inhibitors we have used had either a detrimental or no effect. However, even though the blade steel was nominally identical to that used previously, some microstructural differences may be present. We feel that the visible rust, which we had not seen before, is an indication that corrosion was increased in the absence of inhibitors. Our conclusions are that corrosion inhibitor does indeed reduce corrosion; the inhibitors we have tested so far do not sufficiently reduce corrosion; and the difference in lots of steel is sufficient that blade lifetime in Test #2-3-32 cannot be directly compared with blade lifetime in previous water based slurry tests.

The problems of water based slurries are also discussed in section 2.4.

2.3 Prototype Tests

Continuing our initial testing of the large capacity prototype, we ran Test #2-7-02. Again, safe conditions were chosen: 125 blades, 0.2 mm (0.008 inch) thick, spaced 0.41 mm (0.016 inch) apart were used. The force control system was still inoperative, so a safe cut rate of 0.85 μm/sec (0.002 in/min) was selected. This test was intended to check some minor adjustments in the drive system and bladehead support.

After consulting with JPL, we decided to terminate the run 1/4 of the way through the cut and replace it with a full capacity test, #2-7-03. For this run we used our standard blade pack, 0.15 mm (.006 inch) thick blades spaced 0.36 mm (0.14 inch) apart. 975 blades were used, cutting an ingot 495 mm (19.5 inch) long.

A major problem occurred in the setup. The tensioning mechanism, as discussed earlier, is a toggle clamp type (two opposing corners of a diamond-shaped linkage are drawn together by a bolt, forcing the other two corners apart). The lengths of two adjacent arms are adjustable by wedge blocks. The wedge blocks as received were slightly too large, but were used in the first two runs since the higher mechanical advantage obtained when the corners come close together was not necessary to tension the small packs we were using.

For the full capacity run, we needed the maximum mechanical advantage, so we ground the wedge blocks. We assembled the tensioning mechanism and set the arm length to give an extension of 3.05 mm (0.120 inch) with no blades in the head (there are springs built in to give some resistance to extension). The 20% extra extension was to allow for better pivot seating with the extra force required for a full pack.

Unfortunately, the amount of pivot seating was grossly underestimated; in addition, the arms on one side were slightly unequal in length. Although we monitored the clamp positions during tensioning to avoid locking the toggle linkages by making them too straight, one side straightened completely at 70% of desired elongation, and resisted all our efforts to unlock it.

The only way to unlock the clamp was to cut all the blades to remove the locking force. Here again events conspired against us: a recent, unexpected blade pack order had depleted our supply of the 0.15 mm (0.06 inch) thick blade stock. The pack in the machine had been assembled by tearing down inventoried packs. A new stock of steel had entered customs, and was not expected in the plant for 5 days, by which time the yearly 2 week plant refurbishment shutdown would have started, and pack assembly area would not be working. Since we could not obtain more blade packs for about 3 weeks, we decided to run with the low blade tension we had obtained.

The run was started and we found that our normal sheet-type slotted slurry distribution pipe could not reach the edges of the pack. Wafer breakage started at the ends, and by the time the run was through all wafers were broken. However, we feel that the tensioning and slurry distribution problems were sufficient alone to account for the breakage. The fact that breakage did not start in the center, where the worst-aligned blade is expected, indicated that blade alignment may not be the limiting factor in use of the large prototype.

Test #2-7-04 was run using the same parameters as #2-7-03, and was also a full capacity test. The tensioning mechanism was properly adjusted, and full tension was achieved easily. A slurry dispenser tube with many small holes instead of a slot was used. This dispenser was acceptable but tended to clog, so a better solution for slurry dispensing must be found.

The run was extremely successful almost all the way through. Yield was 99%+ up to the last 10 minutes of the cut, at which point many wafers broke loose from the submount. Final yield was 36%. Cutting time was 36.7 hours. The wafers were quite good; bow was 66 μm (.0026 in.) and taper was 82 μm (.0032 in.).

When we inspected the submount where the wafers had broken away, the submount proved to be clean of adhesive. Either insufficient adhesive was applied or the adhesive weakened from being held at working temperature too long. In either case, the run would have been extremely successful but for our error in bonding the work to the submount. As it was, the run was moderately successful. We will re-examine our bonding materials and techniques.

2.4 Other Progress

The electronic, closed loop force control system on the large prototype saw was removed, rebuilt, and bench tested. Performance was excellent. When we reinstalled the system in the saw, performance was significantly degraded due to ground loops and inductive noise pickup from nearly 110 VAC lines. We are currently working on eliminating this noise pickup.

The bounce fixture modification for the 686 saw is also proceeding. The new bounce fixture has been completed and installed. Compared to the first model, the new fixture has even lower mass, which will further reduce the end-of-stroke shock loads. It is now contained completely below the ingot, so the maximum cuttable ingot width is not reduced. It is also completely enclosed and protected from slurry.

Since the isolation of the vibration from the air cylinder caused feed sticking with the first bounce fixture, we have decided to replace the air cylinder feed with an electric motor, lead screw, force sensor, and closed loop control similar to those used in the lab saw and prototype. This system has now been fabricated and is being installed.

As reported earlier, water based slurry vehicles are attractive from the standpoints of convenience and cost. Blade breakage has prevented their use. We hired a consultant, Prof. R. M. Latanision of M.I.T. (Director of the Corrosion Laboratory) to investigate the blade failures. Based on observation of the process and broken blades, he concluded that the fractures were caused by hydrogen embrittlement, the hydrogen resulting from corrosion. (He felt that the fracture surfaces are such excellent examples of hydrogen embrittlement fracture that he requested samples to use in class.) His opinion was that no corrosion inhibitor is available which would solve the problem: the solution would be to reduce blade hardness and/or change blade material. Since none of these alternatives is acceptable at the moment, we are suspending work on water based slurry.

Two manufacturers of filters attempted to separate Si and SiC by filtration from the sludge obtained from the mineral oil slurry tests. In both cases, all particles passed through the filter before a cake was built up and the filter reached full efficiency.

In view of the large difference in particle sizes (Si $<1\mu m$, SiC $\approx$ 10 to 30 μm) and specific gravities (Si = 2.33, SiC = 3.22), we feel that the separation problem is not a technological one, but is merely one of finding the right system among the many that exist. We will continue work along these lines.

We have investigated the question of the optimum amount of silicon to remove after sawing, to gain maximum efficiency with minimum material waste. 2x2 cm wafers were etched in either Nitric-HF (planar etch) or Transene Solar Cell Etchant 100 (texture etch). Details of the procedures will be found in our earlier quarterly reports.

The wafers were fabricated into solar cells by an outside vendor. Cells were manufactured with AR coating. The cells were tested under AMO conditions with illumination of 135.3 mW/cm^2 at

28°C. The results are presented in Figures 1 and 2 and the raw data is contained in Appendix I. (Some of the data from Appendix I was discarded in preparing Figures 1 and 2. "Outliers", the extreme values, were checked by computing the ratio of the standard deviations with and without each outlier. This statistic is tabulated. Outliers with less than 5% significance were rejected and the process repeated until no further outliers could be rejected.)

The efficiencies obtained are somewhat low and their range is somewhat high. However, the control (ID sawn) wafers for each group obtained average efficiencies of only 11.5% (4 wafers). It is likely that process optimization would allow fabrication of slurry sawn wafers as good as the ID sawn wafers.

The most significant result shown in both Figures 1 and 2 is that the optimum removal amount is in the range 5-15 μm per side. This agrees with previous work done at JPL and is extremely significant to the economics of the slurry sawing process.

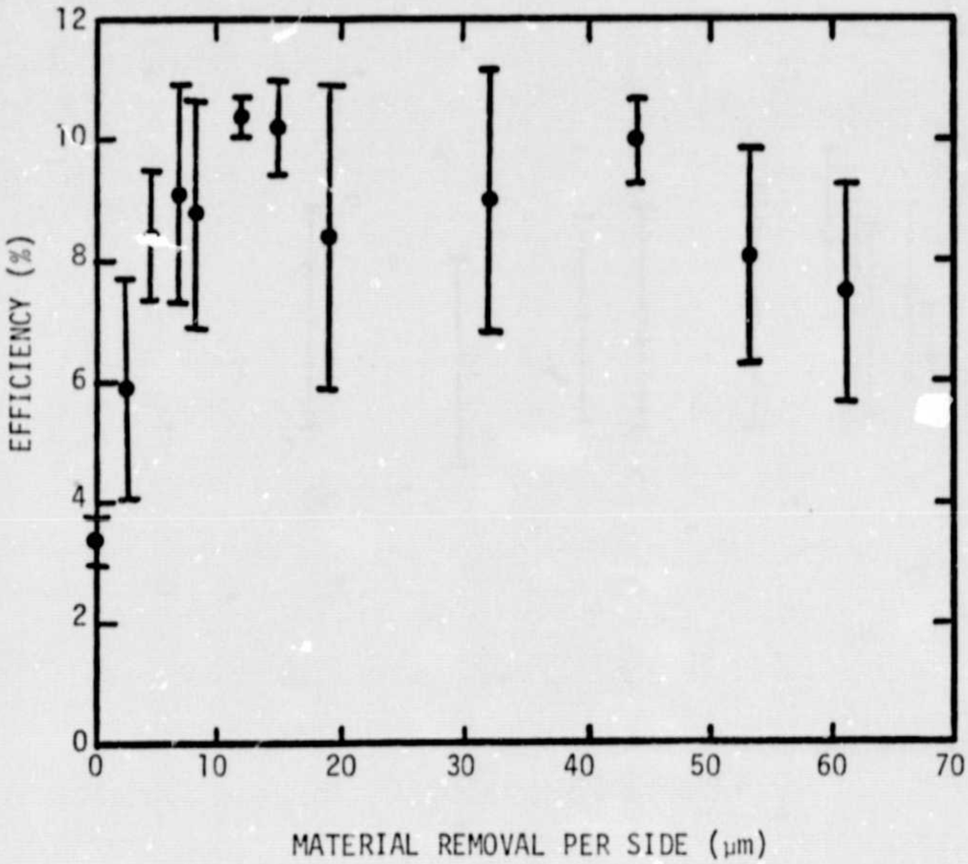


FIGURE 1. EFFICIENCY vs. MATERIAL REMOVED IN NITRIC-HF PLANAR ETCH (BARS INDICATE STANDARD DEVIATION)

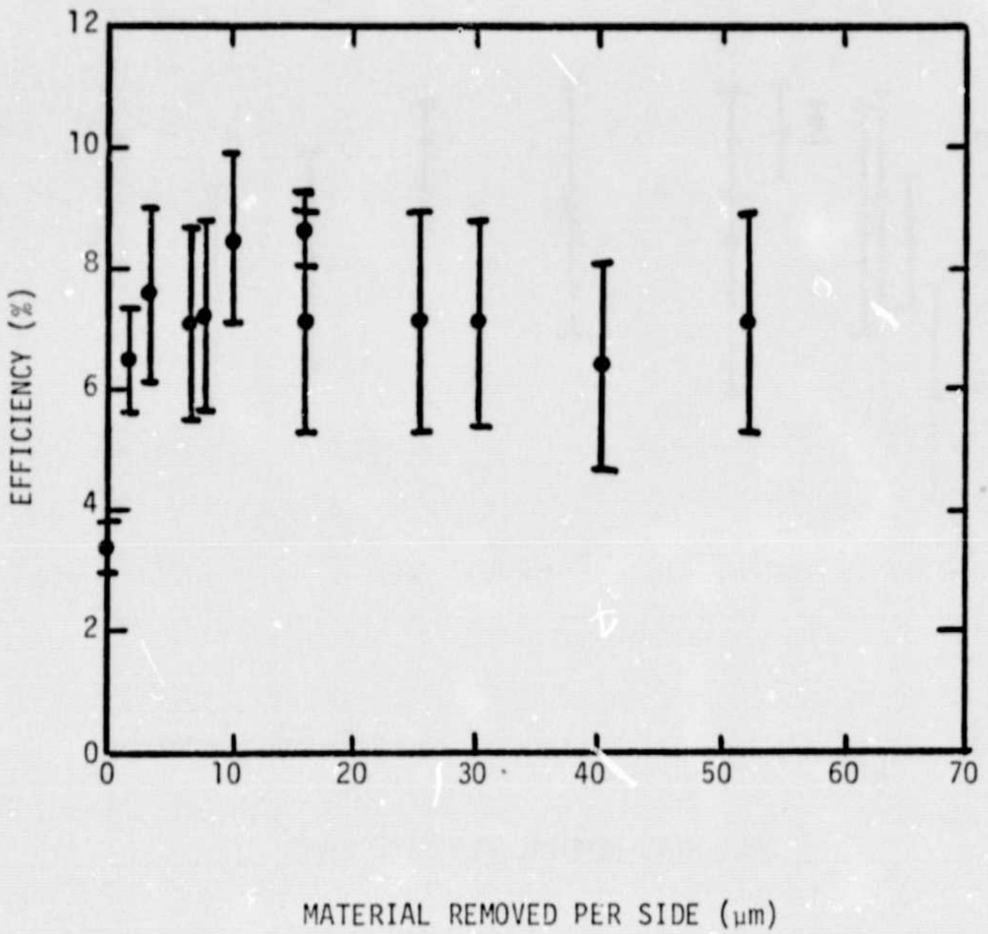


FIGURE 2. EFFICIENCY vs. MATERIAL REMOVED IN TRANSENE SOLAR CELL ETCH 100 (TEXTURE ETCH) (BARS INDICATE STANDARD DEVIATION

3.0 PROBLEMS

- Problems in the technique of using the prototype large saw have been encountered: none of them are sufficiently difficult to call the design to question.
- Due to increased orders for blade packs, we have been forced to order packs earlier than we have been accustomed to. This makes it more difficult to change plans and test sequences, but does not significantly affect the overall effort.

4.0 PLANS

Plans for the next quarter include:

- Testing the prototype saw force control system.
- Completion of the "qualification test" phase of prototype saw testing.
- Testing the prototype saw with thin blades, high reciprocation rates, etc.
- Further testing of mineral oil/lubricity additive slurry vehicles.
- Further testing of T-1 thickness tolerance blades.
- Testing the new bounce fixture.
- Investigation of more abrasive recycling methods.

APPENDIX I

TABLE AI

EFFICIENCIES FOR WAFERS ETCHED IN PLANAR ETCH. (DASHES INDICATE BROKEN WAFERS. UNDERLINES INDICATE WAFERS IGNORED AT 95%+ CONFIDENCE LEVEL.)

LOT	P-007-01	P-007-02	P-007-03
AMOUNT REMOVED (per side)	0 μm	2.6 μm	4.6 μm
WAFER			
1	3.7	- -	- -
2	3.3	- -	8.6
3	2.6	6.1	9.7
4	5.7	7.1	- -
5	- -	7.5	7.4
6	2.9	4.2	6.1
7	2.9	3.0	- -
8	3.7	7.5	9.5
9	3.8	- -	9.1
10	3.1	8.9	8.7
11	3.2	4.3	9.5
12	- -	7.7	7.8
13	3.3	- -	6.7
14	1.9	7.0	8.3
15	- -	6.5	9.7
16	8.6	2.4	8.8
17	3.6	6.3	9.0
18	3.6	5.4	8.1
19	3.7	4.2	7.1
20	3.6	5.6	- -
MEAN	3.4	5.9	8.4
STD. DEV.	0.4	1.8	1.1

TABLE AI
(continued)

EFFICIENCIES FOR WAFERS ETCHED IN PLANAR ETCH. (DASHES INDICATE BROKEN WAFERS. UNDERLINES INDICATE WAFERS IGNORED AT 95%+ CONFIDENCE LEVEL.)

LOT	P-007-04	P-007-05	P-007-06	P-007-07
AMOUNT REMOVED (per side)	7.0 μm	8.1 μm	12 μm	15 μm
WAFER				
1	10.3	10.4	10.6	10.6
2	9.3	10.7	11.0	- -
3	6.0	- -	10.1	10.5
4	10.2	9.2	10.8	10.5
5	5.6	8.8	10.1	8.3
6	9.8	8.6	10.0	10.5
7	7.1	- -	10.5	10.5
8	10.4	7.6	- -	10.9
9	9.8	7.8	10.5	10.2
10	6.4	10.4	10.7	11.0
11	10.4	- -	10.4	10.2
12	- -	6.6	10.7	11.0
13	10.6	10.5	10.7	10.4
14	8.3	- -	10.4	10.8
15	10.7	10.1	- -	8.8
16	10.4	10.3	6.4	9.0
17	6.7	6.3	10.2	10.6
18	10.1	9.5	10.2	9.8
19	9.6	4.2	10.2	9.7
20	10.5	10.5	8.6	10.0
MEAN	9.1	8.8	10.4	10.2
STD. DEV.	1.8	1.9	0.3	0.8

TABLE AI
(concluded)

EFFICIENCIES FOR WAFERS ETCHED IN PLANAR ETCH. (DASHES INDICATE BROKEN WAFERS. UNDERLINES INDICATE WAFERS IGNORED AT 95%+ CONFIDENCE LEVEL.)

LOT	P-007-08	P-007-09	P-007-10	P-007-11	P-007-12
AMOUNT REMOVED (per side)	19 μm	32 μm	44 μm	53 μm	61 μm
WAFER					
1	10.8	8.5	10.1	- -	6.0
2	10.5	11.0	8.6	8.3	9.7
3	10.6	11.0	- -	9.6	4.9
4	6.4	9.6	10.8	8.2	8.3
5	6.6	11.1	11.0	6.2	10.1
6	4.5	4.9	5.4	- -	6.9
7	- -	8.4	11.3	8.8	5.9
8	- -	10.9	10.2	8.3	8.6
9	6.9	9.5	9.3	6.9	6.0
10	- -	9.5	8.5	6.5	7.5
11	5.6	11.0	8.8	8.2	- -
12	10.3	11.0	- -	9.6	7.5
13	- -	10.5	11.1	9.2	10.0
14	- -	5.8	8.0	7.0	9.4
15	11.1	5.0	8.8	7.0	5.7
16	6.1	- -	10.2	10.7	4.9
17	10.5	9.5	11.0	10.3	10.2
18	10.0	5.8	10.5	10.6	6.7
19	11.0	7.7	11.0	3.8	7.1
20	4.8	10.7	10.2	6.4	7.8
MEAN	8.4	9.0	10.0	8.1	7.5
STD. DEV.	2.5	2.2	0.71	1.8	1.8

TABLE AII

EFFICIENCIES FOR WAFERS ETCHED IN TRANSENE SOLAR CELL ETCH (TEXTURE ETCH). (DASHES INDICATE BROKEN WAFERS. UNDERLINES INDICATE WAFERS IGNORED AT 95%+ CONFIDENCE LEVEL.)

LOT	P-008-01	P-008-02	P-008-03	P-008-04
AMOUNT REMOVED (per side)	0 μm	1.5 μm	2.9 μm	6.3 μm
WAFER				
1	3.6	6.5	8.3	5.8
2	3.3	- -	6.0	8.4
3	3.0	7.2	6.0	- -
4	- -	5.2	7.9	5.9
5	3.5	- -	- -	5.2
6	3.5	- -	9.7	4.5
7	- -	6.7	6.8	- -
8	4.1	5.9	8.6	- -
9	- -	7.1	5.4	7.1
10	3.1	6.4	8.3	7.6
11	3.4	6.8	7.6	6.1
12	- -	5.2	7.9	- -
13	3.4	7.0	- -	9.4
14	3.9	5.8	8.5	4.3
15	3.7	7.0	9.7	8.6
16	- -	7.2	5.1	7.2
17	2.9	8.5	8.6	9.2
18	3.2	7.0	6.7	6.6
19	- -	5.4	6.3	8.7
20	3.0	6.1	9.2	8.2
MEAN	3.4	6.5	7.6	7.1
STD. DEV.	0.4	0.9	1.4	1.6

TABLE AII
(continued)

EFFICIENCIES FOR WAFERS ETCHED IN TRANSENE SOLAR CELL ETCH (TEXTURE ETCH). (DASHES INDICATE BROKEN WAFERS. UNDERLINES INDICATE WAFERS IGNORED AT 95%+ CONFIDENCE LEVEL.)

LOT	P-008-05	P-008-06	P-008-07	P-008-08
AMOUNT REMOVED (per side)	7.6 μm	10 μm	16 μm	16 μm
WAFER				
1	8.7	9.8	8.2	6.6
2	6.1	9.1	- -	- -
3	- -	- -	- -	8.7
4	6.2	9.9	- -	5.4
5	- -	9.3	8.4	10.0
6	7.3	7.4	9.1	- -
7	8.8	- -	- -	- -
8	- -	6.0	- -	5.3
9	8.4	- -	9.4	8.6
10	- -	8.5	8.4	- -
11	8.1	[illegible].9	5.6	6.2
12	8.1	9.4	- -	7.8
13	- -	8.1	8.3	5.6
14	5.1	8.5	9.9	- -
15	8.3	9.0	9.0	4.1
16	8.8	9.0	9.0	8.1
17	3.9	9.6	8.9	- -
18	7.6	10.3	8.8	8.7
19	8.1	8.6	7.7	8.9
20	4.5	7.8	7.8	4.9
MEAN	7.2	8.5	8.7	7.1
STD. DEV.	1.6	1.4	0.6	1.8

TABLE AII
(concluded)

EFFICIENCIES FOR WAFERS ETCHED IN TRANSENE SOLAR CELL ETCH (TEXTURE ETCH). (DASHES INDICATE BROKEN WAFERS. UNDERLINES INDICATE WAFERS IGNORED AT 95%+ CONFIDENCE LEVEL.)

LOT	P-008-09	P-008-10	P-008-11	P-008-12
AMOUNT REMOVED (per side)	25 μm	30 μm	40 μm	52 μm
WAFER				
1	7.7	10.2	8.8	9.1
2	- -	- -	- -	9.9
3	6.5	- -	5.3	- -
4	10.2	8.6	8.9	6.0
5	- -	- -	- -	6.5
6	6.7	8.1	4.7	5.5
7	9.0	6.4	7.2	- -
8	4.6	7.4	- -	7.6
9	9.5	5.0	- -	8.0
10	7.8	- -	8.2	5.2
11	9.3	7.9	7.5	9.9
12	8.0	3.6	5.5	- -
13	5.9	8.9	5.1	8.8
14	6.9	8.2	- -	- -
15	8.9	6.3	5.1	4.5
16	4.3	5.6	5.0	6.0
17	5.4	7.5	6.2	7.4
18	5.4	7.5	4.5	6.7
19	6.9	5.8	9.2	4.3
20	4.5	- -	5.3	8.5
MEAN	7.1	7.1	6.4	7.1
STD. DEV.	1.8	1.7	1.7	1.8

APPENDIX II

SLICING TEST SUMMARY

PARAMETER	TEST	2-1-08	2-1-09	2-1-10	
Material		100 Si	100 Si	100 Si	
Size	(mm)	100	100	100	
Area/Slice	(cm^2)	78.5	78.5	78.5	
Blade Thickness	(mm)	0.15 x 6.35	0.15 x 6.35	0.15 x 6.35	
Spacer Thickness	(mm)	0.36	0.36	0.36	
Blade Height	(mm)	6.35	6.35	6.35	
Number of Blades				145	
Load	(gram/blade)			85	
Sliding Speed	(cm/sec)			61.7	
Abrasive	(type/grit size)	#600 SiC	#600 SiC	#600 SiC	
Oil Volume	(liters)	7.6 PC	7.6 PC	7.6 PC	
Mix	(kg/liter)	0.36	0.36	0.36	
Slice Thickness	(mm)			0.287	
Kerf Width	(mm)			0.221	
Abrasive Kerf Loss	(mm)			0.071	
Cutting Time	(hours)			41.33	
Efficiency	(full test)			0.8037	
	(typical)			0.9916	
	(maximum)			1.3894	
Abrasion Rate	(full test)			0.042	
(cm^3/hr/bl)	(typical)			0.052	
	(maximum)			0.073	
Productivity	(full test)			1.90	
(cm^2/hr/bl)	(typical)			2.35	
	(maximum)			3.30	
Yield		0%	0%	130/144 90%	
Slice Taper	(mm)			0.052	
Slice Bow	(mm)			0.046	
Abrasive Utilization	(cm^3/kg)			92.03	
Oil Utilization	(cm^3/liter)			33.13	
Blade Wear Ratio	(cm^3/cm^3)			0.047	

SLICING TEST SUMMARY

PARAMETER TEST	2-3-20	2-3-22	2-3-23	
Material	100 Si	100 Si	100 Si	
Size (mm)	100	100	100	
Area/Slice (cm^2)	78.54	78.54	78.54	
Blade Thickness (mm)			0.15 x 6.35	
Spacer Thickness (mm)			0.36	
Blade Height (mm)			6.35	
Number of Blades			150	
Load (gram/blade)			85	
Sliding Speed (cm/sec)			62.10	
Abrasive (type/grit size)			#600 SiC	
Oil Volume (liters)			7.6 Min.Oil/Lubricity	
Mix (kg/liter)			0.36	
Slice Thickness (mm)			0.266	
Kerf Width (mm)			0.242	
Abrasive Kerf Loss (mm)			0.092	
Cutting Time (hours)			36.75	
Efficiency (full test)			0.9886	
(typical)			1.3175	
(maximum)			1.6590	
Abrasion Rate (full test)			0.052	
(cm^3/hr/bl) (typical)			0.069	
(maximum)			0.087	
Productivity (full test)			2.14	
(cm^2/hr/bl) (typical)			2.85	
(maximum)			3.59	
Yield			18/150 12%	
Slice Taper (mm)			0.120	
Slice Bow (mm)			0.118	
Abrasive Utilization (cm^3/kg)			104.17	
Oil Utilization (cm^3/liter)			37.50	
Blade Wear Ratio (cm^3/cm^3)			0.042	

SLICING TEST SUMMARY

PARAMETER	TEST	2-3-25	2-3-26	2-3-27**	(see comments)
Material		100 Si	100 Si	100 Si	
Size	(mm)	100	100	100	
Area/Slice	(cm^2)	78.5	78.5	78.5	
Blade Thickness	(mm)	0.15 x 6.35	0.15 x 6.35	0.15 x 6.35	
Spacer Thickness	(mm)	0.36	0.36	0.36	
Blade Height	(mm)	6.35	6.35	6.35	
Number of Blades		150	150	146	
Load	(gram/blade)	85	85	85	
Sliding Speed	(cm/sec)	61.03	63.39	63.57	
Abrasive	(type/grit size)	#600 SiC	#600 SiC	#600 SiC	
Oil Volume	(liters)	7.6 Lard/M.oil	7.6 100 SUS M. Oil	7.6 Lard/Min. Oil	
Mix	(kg/liter)	0.36	0.36	0.48	
Slice Thickness	(mm)	0.282	0.238	0.263	
Kerf Width	(mm)	0.226	0.270	0.245	
Abrasive Kerf Loss	(mm)	0.076	0.120	0.095	
Cutting Time	(hours)	61.0	61.08	26.42	
Efficiency	(full test)	0.561	0.6519	1.356	
	(typical)	0.804	1.0009	1.383	
	(maximum)	1.2593	3.8872	1.8459	
Abrasion Rate	(full test)	0.029	0.035	0.073	
(cm^3/hr/bl)	(typical)	0.042	0.054	0.074	
	(maximum)	0.065	0.209	0.099	
Productivity	(full test)	1.287	1.29	2.971	
(cm^2/hr/bl)	(typical)	1.860	2.00	3.025	
	(maximum)	2.879	7.74	4.047	
Yield		73/150 49%	109/149 73%	7/146 5%	
Slice Taper	(mm)	0.092	0.102	0.047	
Slice Bow	(mm)	0.128	0.128	0.038	
Abrasive Utilization	(cm^3/kg)	97.19	116.19	76.85	
Oil Utilization	(cm^3/liter)	34.99	41.83	36.89	
Blade Wear Ratio	(cm^3/cm^3)	0.049	0.049	0.042	

WAFER THICKNESS CHARACTERIZATION SUMMARY

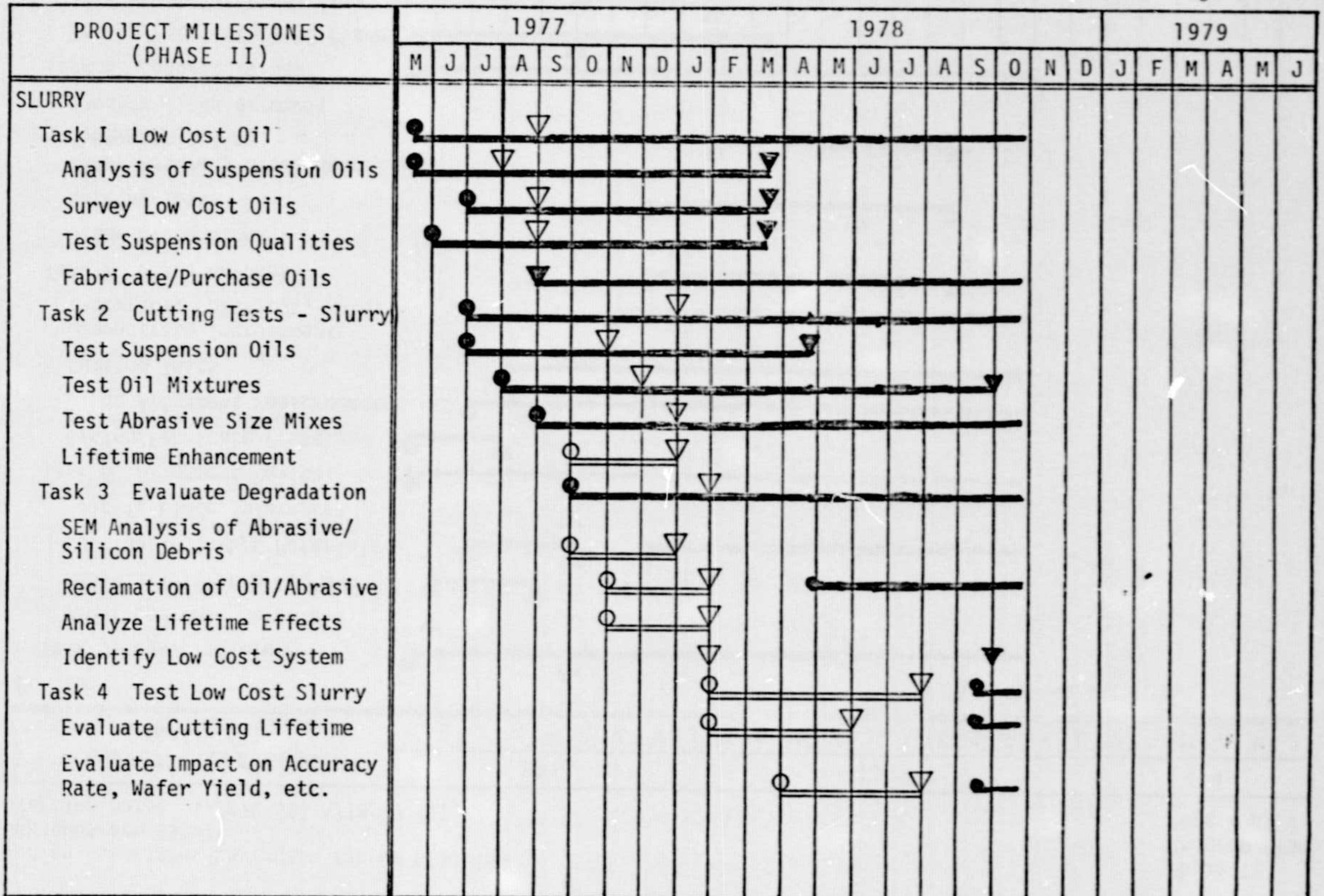
PARAMETER	TEST		2-7-02	2-7-03	2-7-04	
SLICE	Diameter	(mm)		100	100	
	Area	(cm^2)		78.5	78.5	
THICKNESS	Average	μ			299.3	
	Std. Dev.	μ			28.2	
TOTAL VARIATION	Average	μ			72.1	
	Std. Dev.	μ			40.9	
STD. DEVIATION	Average	μ			27.3	
	Std. Dev.	μ			18.0	
VERTICAL TTV	Average	μ			82.4	
	Maximum	μ			156.9	
	Minimum	μ			21.1	
HORIZONTAL TTV	Average	μ			15.0	
	Maximum	μ			33.6	
	Minimum	μ			3.1	
VERTICAL BOW	Average	μ			63.5	
	Maximum	μ			96.3	
	Minimum	μ			29.8	
HORIZONTAL BOW	Average	μ			17.0	
	Maximum	μ			32.1	
	Minimum	μ			4.4	
VERTICAL CL BOW	Average	μ			132.0	
	Maximum	μ			205.8	
	Minimum	μ			83.2	
HORIZONTAL CL BOW	Average	μ			26.7	
	Maximum	μ			78.5	
	Minimum	μ			7.8	

MAN-HOURS AND COSTS (PHASE II)

During the reporting period of June 19, 1978 to October 27, 1978, total man-hours were 2056 hours and total costs were \$56,660. Previous expenditures were 11136.7 hours and \$531,480. As of October 27, 1978, total program man-hours were 13192.7 hours and total program costs were \$588,030.

SLICING OF SILICON INTO SHEET MATERIAL

Varian Associates/Lexington Vacuum Division
JPL Contract 954374
Starting Date: 1/9/76 (I) 5/19/77 (II)



SCH 6/15/77
Updated 11/20/78

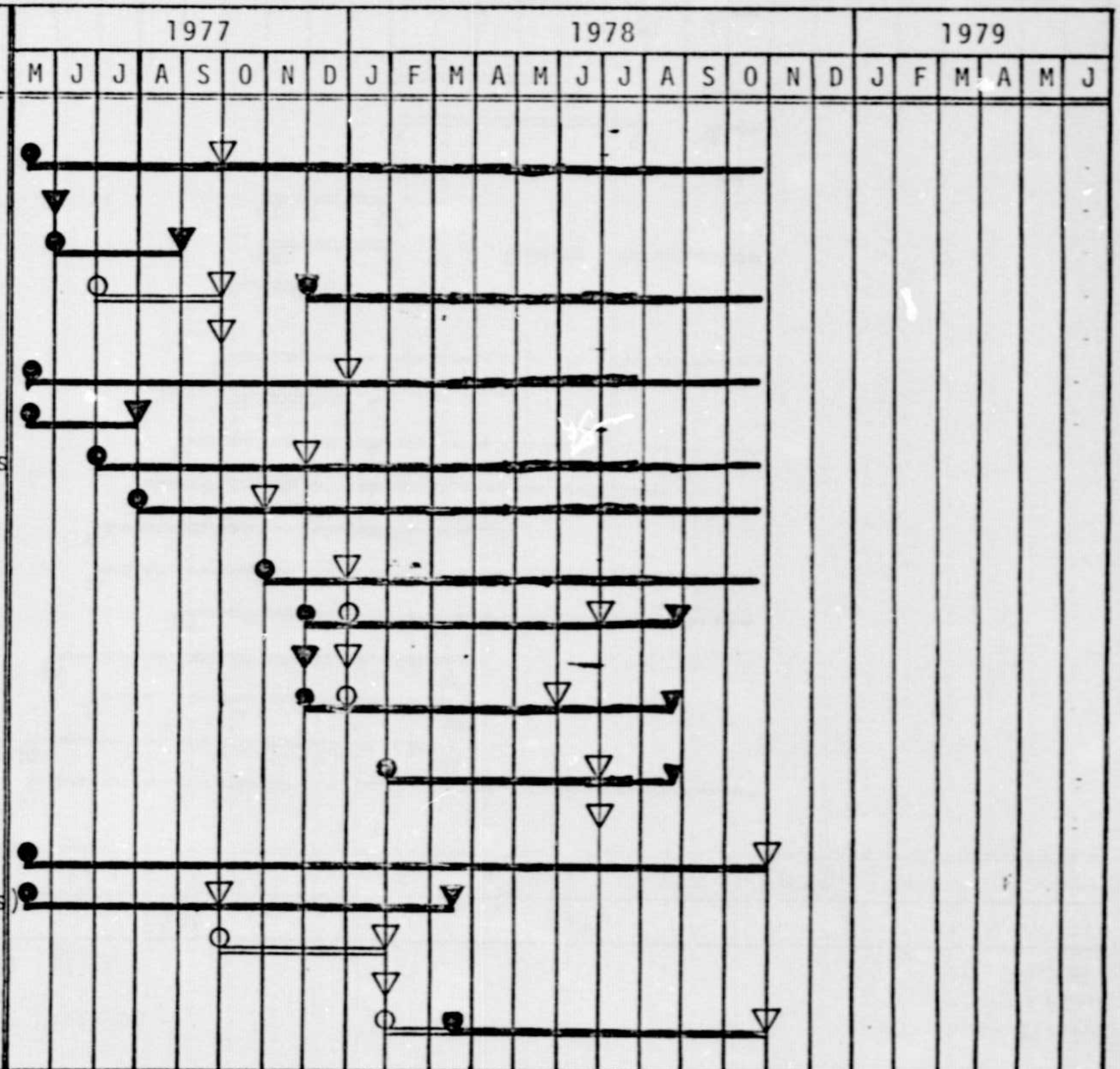
SLICING OF SILICON INTO SHEET MATERIAL

Varian Associates/Lexington Vacuum Division
JPL Contract 954374
Starting Date: 1/9/76 (I) 5/19/77 (II)

Phase II
Program Plan
Page 2 of 8

PROJECT MILESTONES
(PHASE II)

BLADES
- Task 5 Low Cost Blades
  - Order Low Cost Materials
  - Analyze Tolerance Req'mts
  - Cutting Tests-L/C Materials
  - Specify Blade Tolerances
- Task 6 Alignment Device
  - Design/Fabricate Prototype
  - Blade Alignment Measurements
  - Cutting Tests
  - Demonstrate Improvements (Accuracy, Thickness, Rate)
- Task 7 Blade Hardness
  - Order Blade Stock
  - Cutting Tests
  - Wafer Accuracy Blade Wear Characterization
  - Specify Blade Hardness
- Task 8 Laboratory Saw
  - Design/Fabricate(1-10 Blades)
  - Test Effect of Blade Size
  - Specify Blade Size
  - Supporting Tests - Misc.



SCH 6/15/77
Updated 11/20/78

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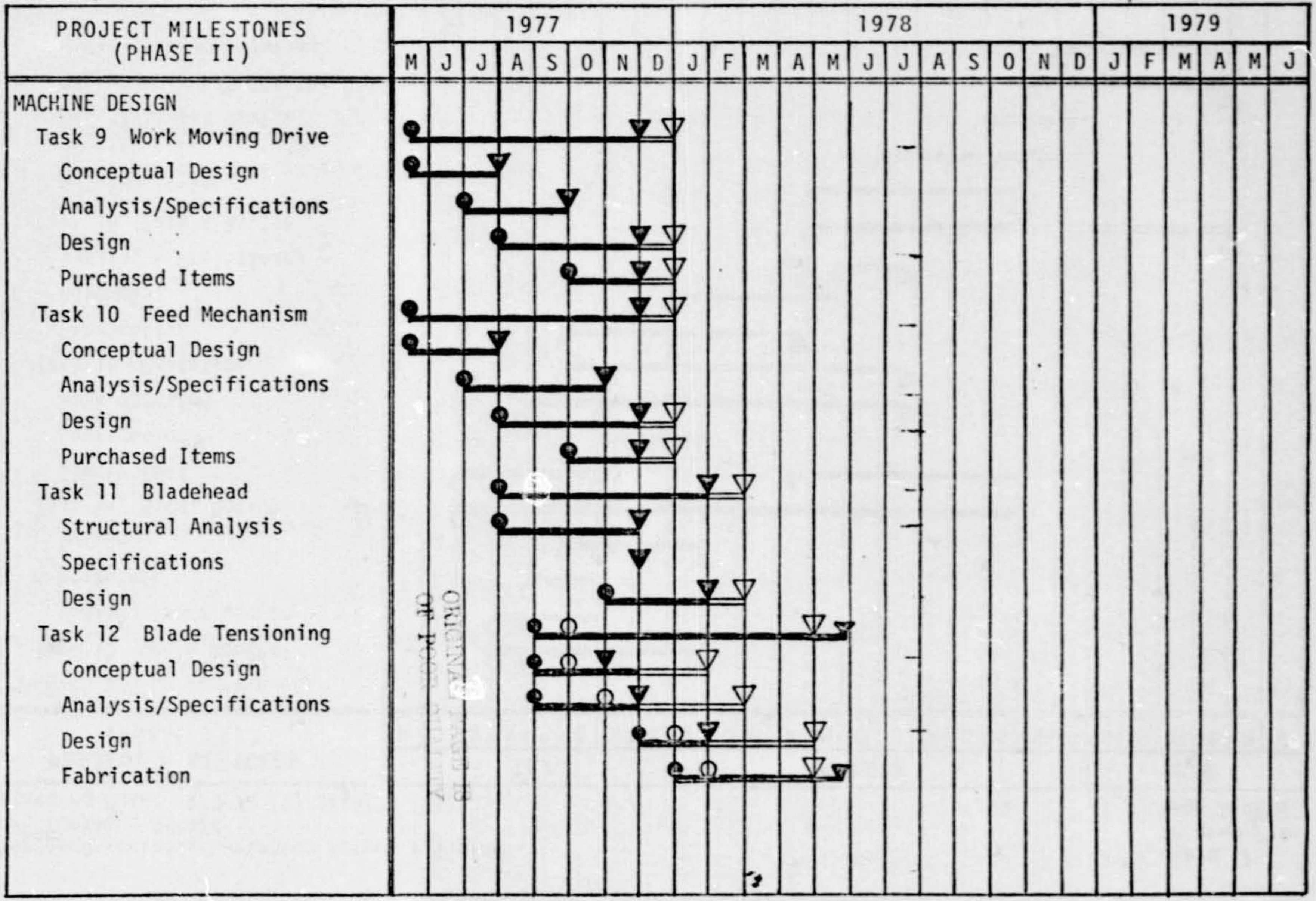

SCH 6/15/77
Updated 11/20/78

SLICING OF SILICON INTO SHEET MATERIAL

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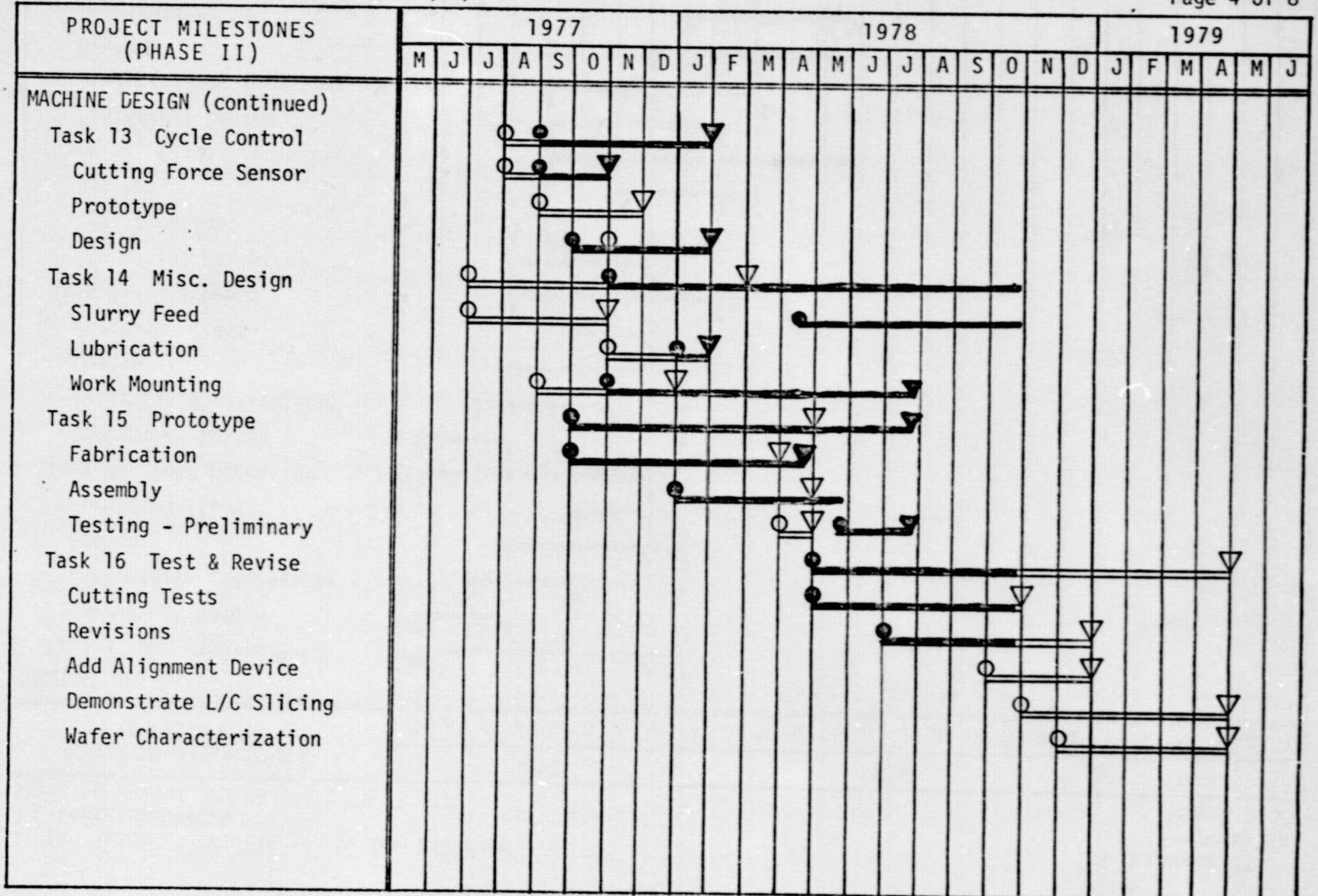
Phase II
Program Plan



SCH 6/15/77
Updated 11/20/78

SLICING OF SILICON INTO SHEET MATERIAL

Varian Associates/Lexington Vacuum Division
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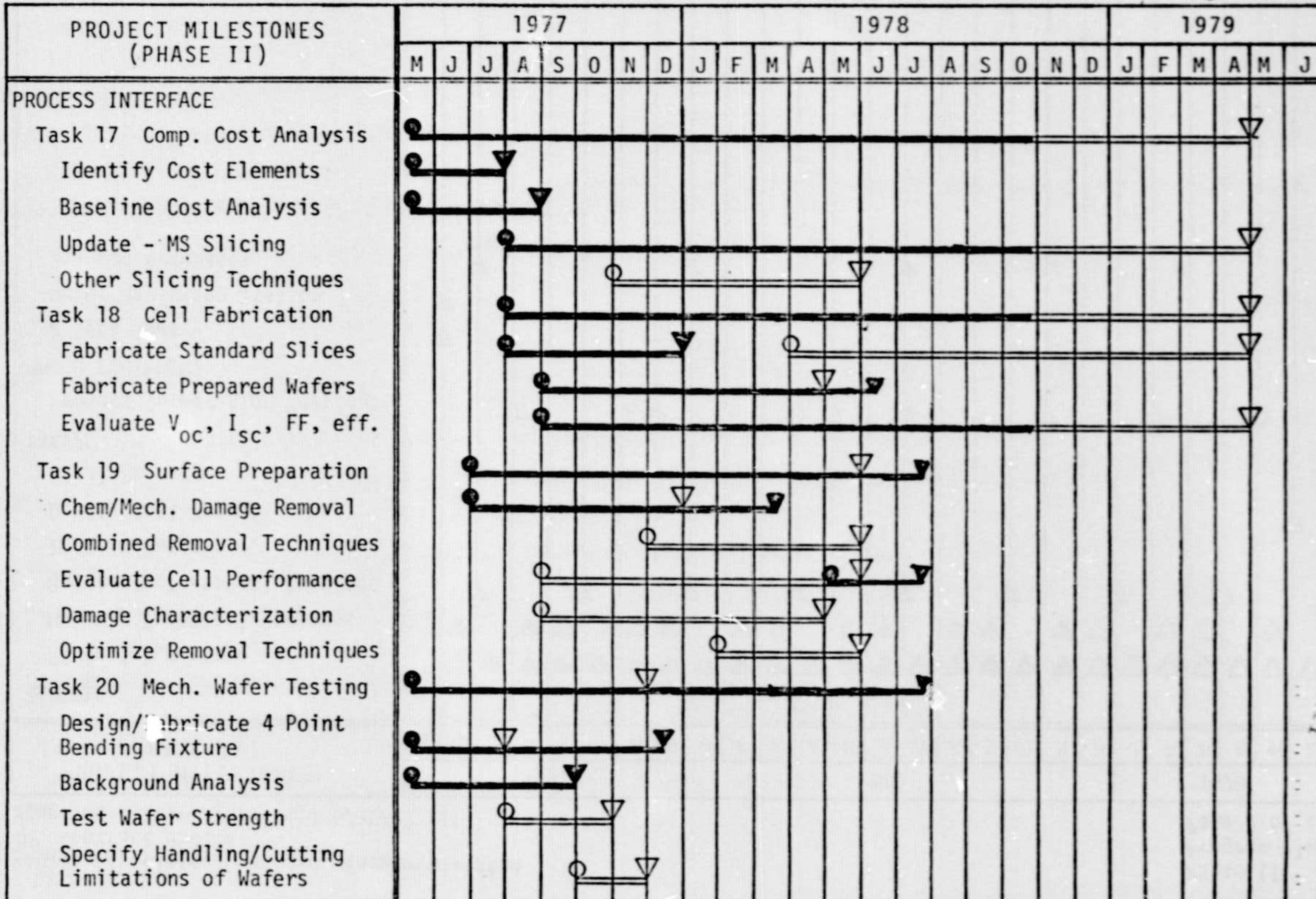
Phase II
Program Plan
Page 5 of 8



SCH 6/15/77
Updated 11/20/78

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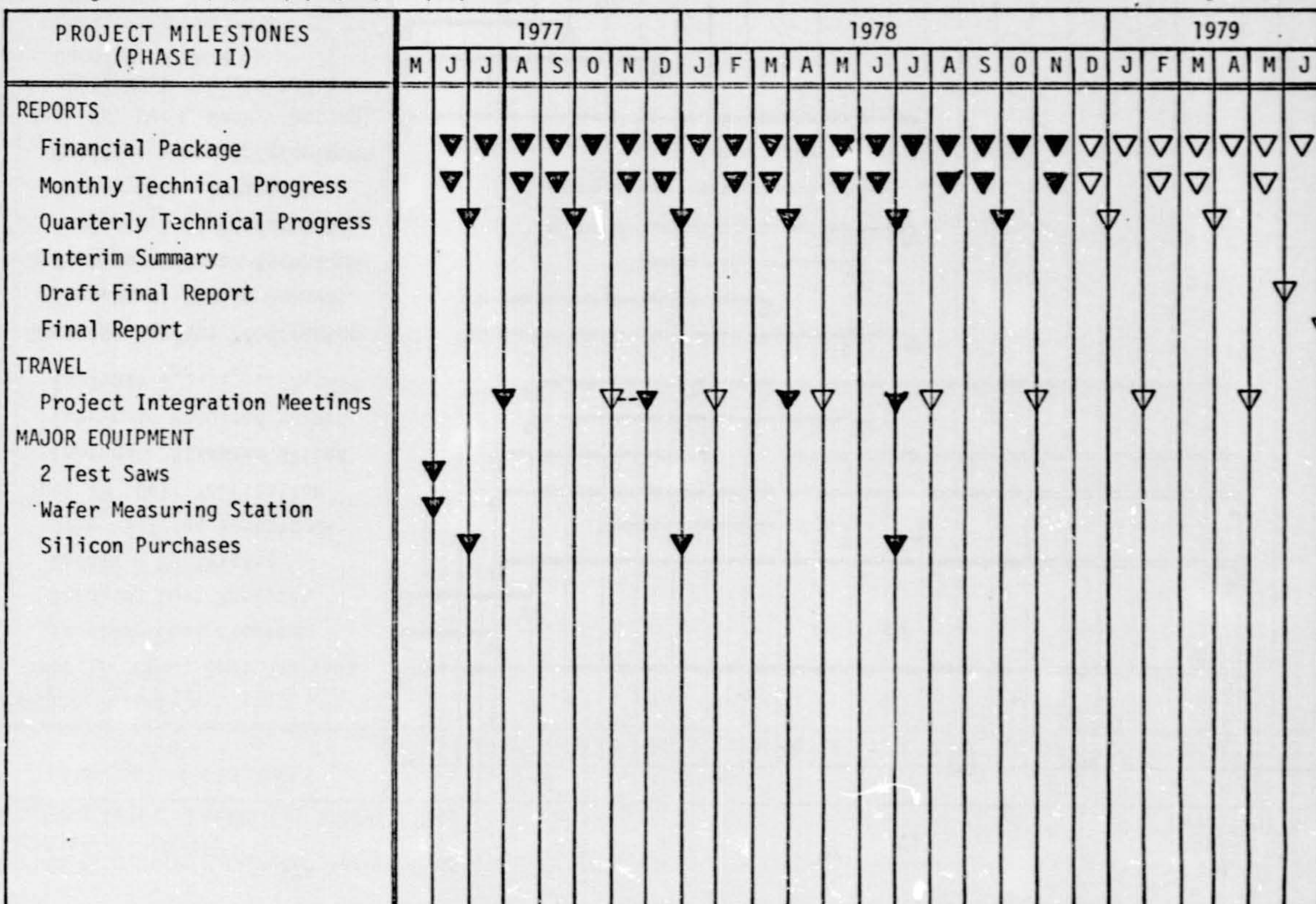
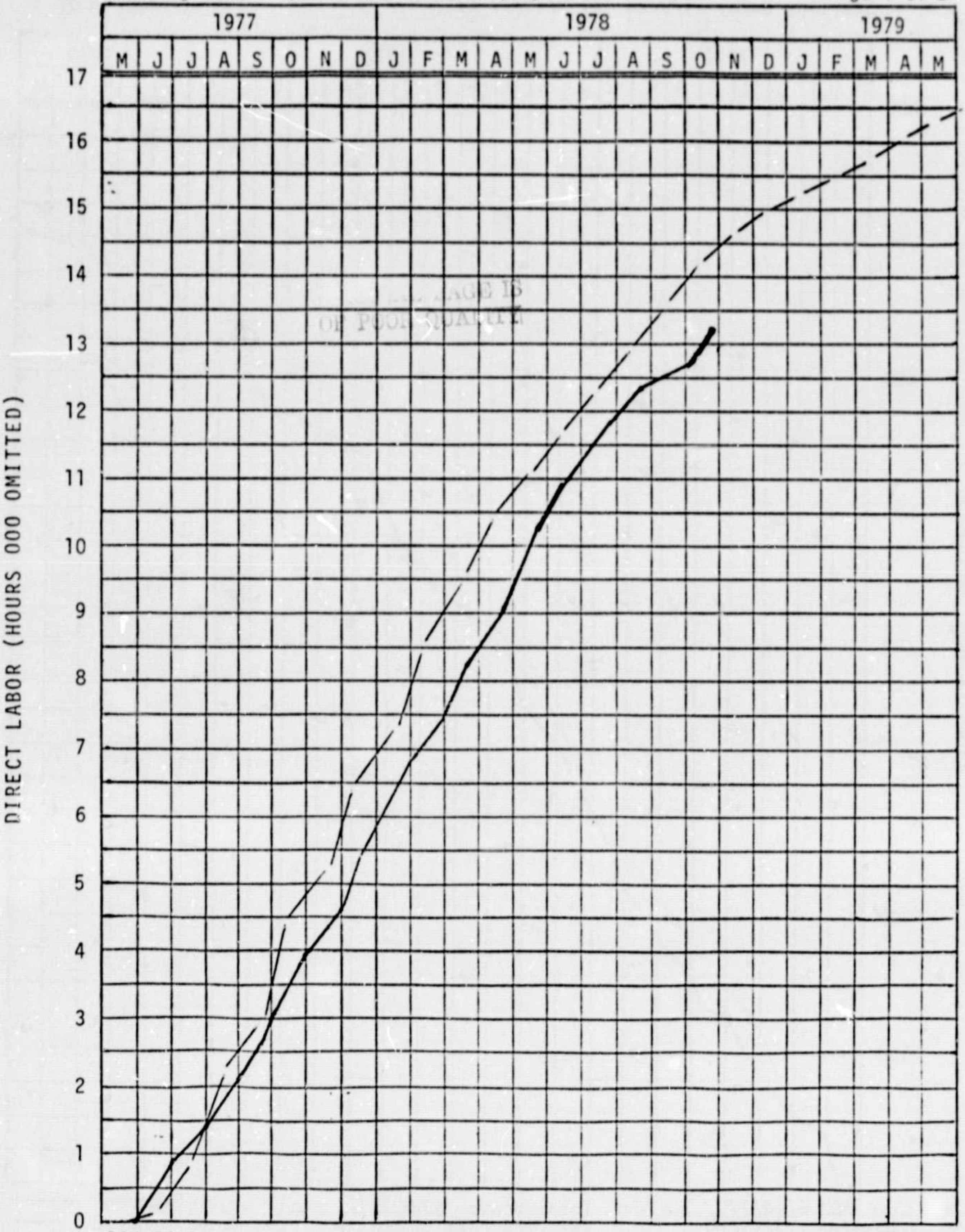


SCH 6/15/77
Updated 11/20/78

SLICING OF SILICON INTO SHEET MATERIAL

Varian Associates/Lexington Vacuum Division
JPL Contract 954374
Starting Date: 1/9/76 (I) 5/19/77 (II)

Phase II
Program Plan



SCH 6/14/77
Updated 11/20/78

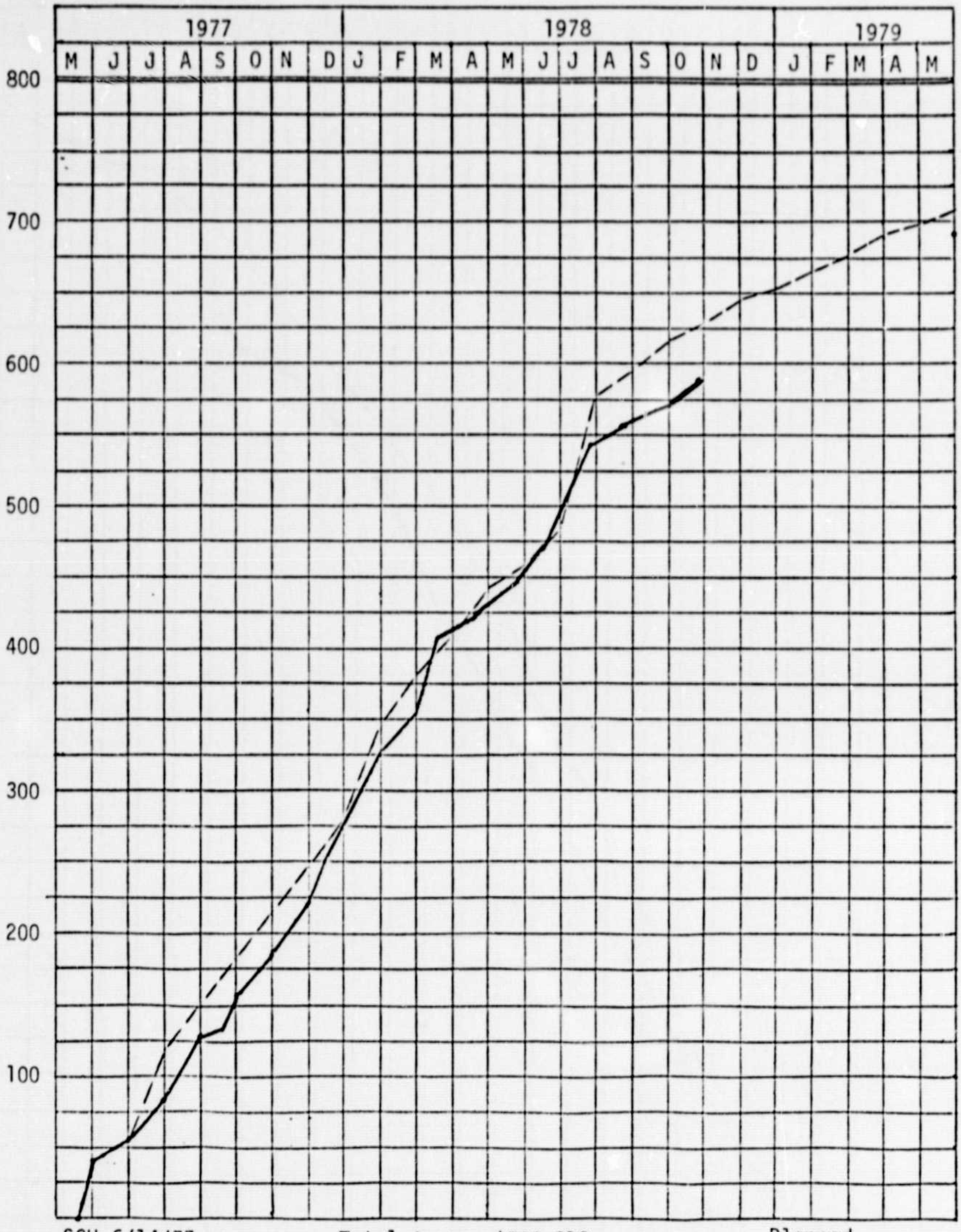
Total Hours: 16,435
Hours to Date: 13,192.7

Planned ------
Incurred ——

PROGRAM LABOR SUMMARY

SLICING OF SILICON INTO SHEET MATERIAL

Varian Associates/Lexington Vacuum Division
JPL Contract 954374
Starting Date: 1/9/76 (I) 5/19/77 (II)



SCH 6/14/77
Updated 11/20/78

Total Cost: $708,210
Incurred Cost: $588,030

Planned -------
Incurred ———

PROGRAM COST SUMMARY